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Spectrometric characteristics of soils of the subboreal zone of the eastern part of the Russian Plain

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ABSTRACT

The use of express methods for assessing of soil degradation degree is a global trend. Numerous studies suggest the possibility of using spectrometric methods for determination of chemical compounds in the soil. In this work, an attempt is made to determine the agrochemical parameters by spectrometric methods for agricultural soils of the subboreal zone of the east of the European Plain. The main types of spectrograms for gray forest soils and leached chernozems were determined and compared with the results of agrochemical analyzes at soil sampling points. The main regularities in indicators change depending on spectrometric curves type are analyzed. The results of the work can be claimed for express determination of agricultural soils degradation degree for a given natural zone.

Keywords: Spectrograms, soil degradation, agrochemical indicators, soil analyzes.

1. INTRODUCTION

Numerous soil studies have shown that soil fertility of agricultural land in most cases is deteriorating due to inappropriate agricultural practices[1,2], water erosion[3], insufficient or excessive fertilization. The latter also leads to groundwater and surface water pollution or chemicals accumulation in soil in dangerous concentrations. The development of principles of agricultural land use that does not allow such negative consequences is the main goal of the so-called precision farming concept, which is aimed at providing the necessary amount of nutrients and moisture characteristics of the soil to maintain optimal growth of agricultural plants. One of the main obstacles of this concept application is the soil cover heterogeneity, often even within the same land plot[4]. As a result, even with the technical feasibility of performing of wide range of analyzes and determining of soil fertility using various methods[4], most of them are rather laborious and in practice do not allow to compare the soil cover properties of farmlands with necessary spatial and/or temporal resolution.

This paper summarizes the use of the express method for determining of soil fertility parameters for agricultural lands, based on spectroscopic physical principles, for zonal soils of the subboreal zone of the East of European Russia, the territory of the Chuvash Republic. Infrared spectroscopy methods, based on the interaction of molecules with electromagnetic energy in the infrared spectrum, are recognized as one of the most promising methods for soils study[5,6,7]. A feature of the mid-infrared range is that it includes the so-called fundamental molecular vibrations. When a molecule absorbs IR radiation at frequencies corresponding to the natural vibrations of the molecules, this leads to an increase in the vibrations amplitude. Since each frequency corresponds to a certain amount of energy and the specific molecules movement (for example, tension, bending of chemical bonds), it is possible to identify in the average IR spectrum the type of molecular movements and functional groups that are present in the molecule. Thus, this information can serve as a unique characteristic of the soil, as well as the human fingerprint in dactyloscopy.

Technological advances in near and middle infrared spectral band application have made it very popular over the past decade in soil research and recognized as one of the most promising non-contact methods for determining soil parameters for various purposes. Most often, these methods are used to assess the trace elements and soil organic matter. Soil mineral elements such as C, N, P, K, S, Ca and trace elements play a high-priority role in crops development and, therefore, their concentrations determining is fundamental for applying the concept of precision farming.

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There is a large number of publications on this topic in foreign scientific literature. One of the best reviews of spectroradiometric research methods published by Rossell et al (2006)[8]. In most studies, carbon is typically determined, in particular organic carbon. The vast majority of studies show very good results of correlation coefficients between actual and estimated values (over 0.9). Good results were obtained for a total nitrogen content (R> 0.80). Despite the fact that some researchers[8] did not find any correlation for nitrates, this conclusion is refuted by good results obtained by other research team[9,10,11] In case of potassium, phosphorus and organic substances, discrepant results have been obtained. In some studies[12,13] the correlation coefficient for potassium concentration was 0.85, in others, relationship degree was lower – R = 0.6[5] and R = 0.76[14]. High correlation was obtained for phosphorus – R=0.87[15] и R=0.81[16]. Despite of the fact, that some studies obtained very good results for organic matter[16,17] with correlation coefficients above 0.90, Canasveras et al[18] identified a very weak relationship between spectral band and organic matter content. In Russia, sporadic attempts have been made to use spectrometric data for soil cover study [19,20,21]. Thus, today the current state of research in this field is controversial. Apparently, there is a need for standardization of soil sampling and analysis, as well as geographical localization for specific types and subtypes of zonal soils[22]. In any case, all foreign researchers emphasize the need of soil properties study by spectrometric methods with an increase of geographical coverage of studied soils.

This work is an attempt to fill the gap in spectrometric studies of zonal soils of the subboreal belt of the eastern part of the Russian Plain[23].

2. METHODS

The study included gray forest soils and leached chernozems affected by long-term agricultural cultivation. Field studies (sampling and spectrometric measurements) were carried out at spring, before the appearance of a large amount of agricultural plants, in order to reduce the influence of vegetation on spectrometric surveys quality. For the field work, several typical soil distribution areas in the Chuvash Republic were selected. Sampling was carried out in areas with a radius of 10 km from points 55º51'N 47º30'E (Tsivil'sky municipal district) and 55º15'N 47º33'E (Komsomol'skiy municipal district), 200 points for each polygon with an interval of 150-200 meters.

Field surveys were carried out with Handheld 2 spectroradiometer and geodetic GPS equipment. In parallel with spectroradiometric surveys, soil samples were selected for their subsequent laboratory studies on the main agrochemical parameters (humus, mobile phosphorus, mobile potassium, pH). In order to systematize the data and determine dependences between the spectrograms types, agrochemical indicators, and soil cover structure, field work was carried out to update the 1:100000 scale soil maps.

Table 1. Distribution of agrochemical indicators by spectrogram types.

Spectrogram sampling points	Soil sample number	Lab. number	Spectrogram type	Organic matter (humus),%	Mobile phosphorus, mg	Mobile potassium, mg	pH (H2O)
1039	№1	129	1	4,9	131	167	5,86
1032	№2	130	1	6,94	88	123	5,92
1027	№3	131	1	6,36	95	111	5,99
1061	№4	132	2	7,17	80	85	6,07
1015	№5	133	1	6,69	71	87	5,93
1048	№8	136	1	6,21	97	83	5,71
1053	№13	141	2	6,52	125	106	6,2
1112	№4	154	4	4,65	207	89	5,44
1115	№5	155	4	4,82	277	162	5,55
1106	№9	159	1	5,2	218	109	5,65
1099	№10	160	3	5,36	210	125	5,68
1066	№370	167	1	4,54	283	129	5,91
1080	№371	168	3	4,73	222	102	5,92
1075	№373	169	1	5,57	256	171	5,93
1076	№372	170	1	5,7	262	148	5,91

3. RESULTS

The spectrometric data (spectrograms) were systematized according to the type of curves and correlated with soil types and varieties and their agrochemical indicators. We have identified 5 types of spectrographic curves in the studied areas. As a result, the following distribution of spectrographic curves for soil varieties was obtained:

1. The spectrographic curve #1 is typical for chernozems leached, medium thickness, medium-humic; dark-grey forest soils with light washout (Fig. 1).

2. The spectrographic curve #2 – for chernozems leached, medium loamy, light washout; chernozems leached, light washout; dark gray forest typical gley soil with light texture (Fig. 2).

3. The spectrographic curve #3 – for chernozems leached, medium thickness, medium-humic; dark-grey forest soils with medium washout (Fig. 3).

4. The spectrographic curve #4 – for dark-grey forest soils with medium washout; for chernozems leached, minor thickness, medium-humic (Fig. 4).

5. The spectrographic curve #5 – for dark-grey forest soils with high washout (Fig. 5).

In order to study the dependences of spectrograms type on agrochemical indicators (humus, mobile phosphorus, mobile potassium, pH), the values of these indicators were compared with each other at sampling points with different types of spectrograms. They are presented in table 1.

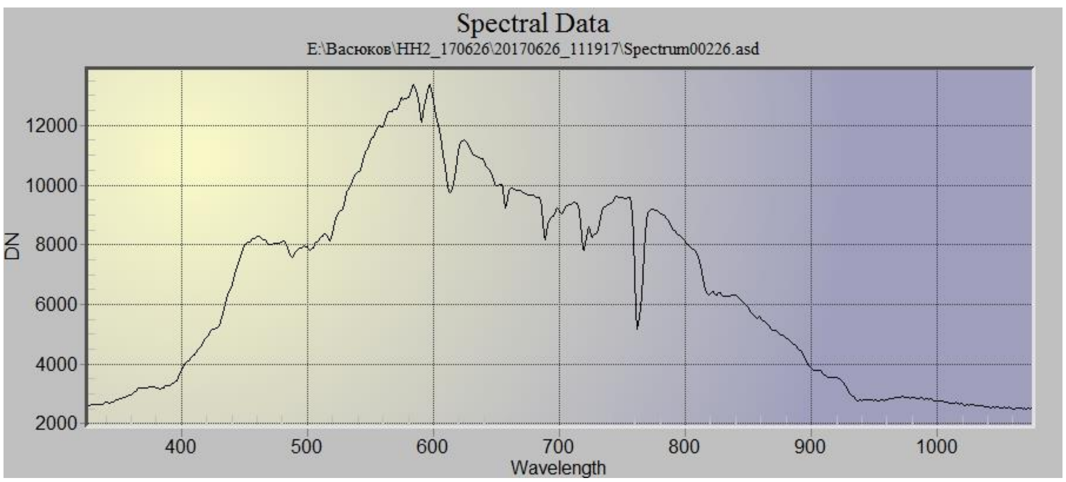

Figure 1. The first type of the spectrographic curve.

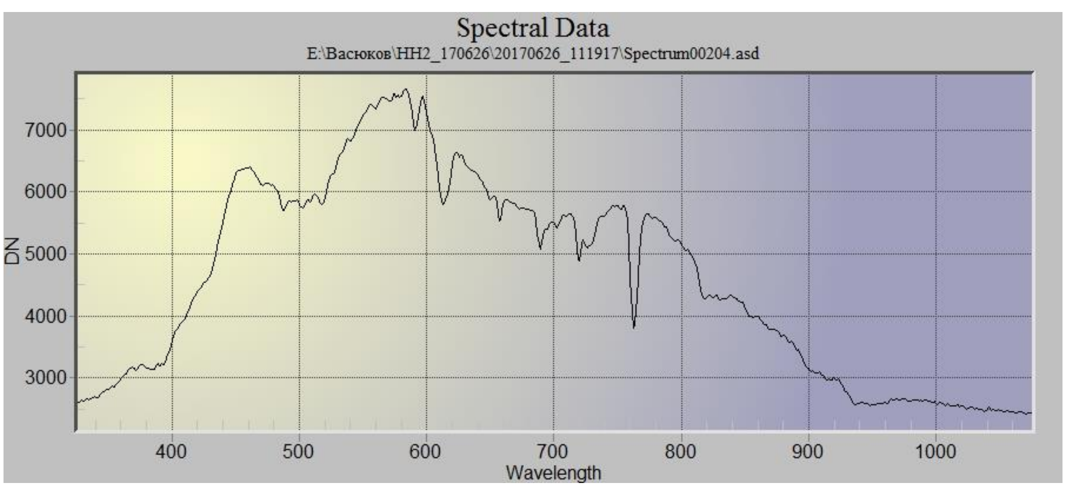

Figure 2. The second type of the spectrographic curve.

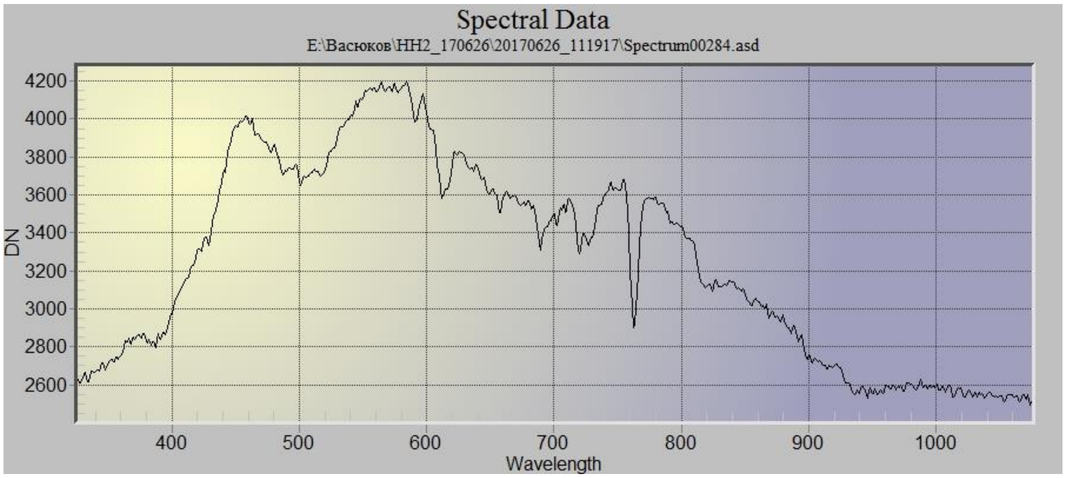

Figure 3. The third type of the spectrographic curve.

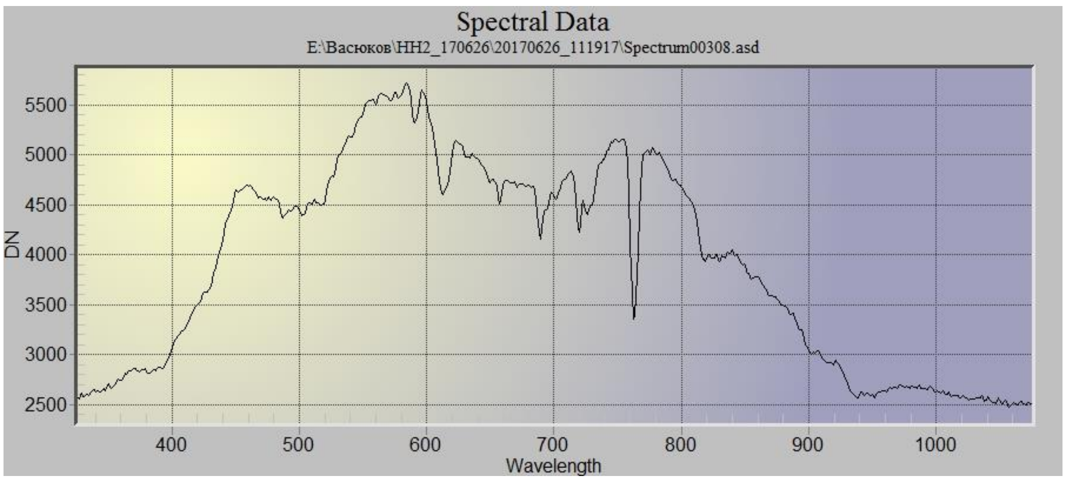

Figure 4. The fourth type of the spectrographic curve.

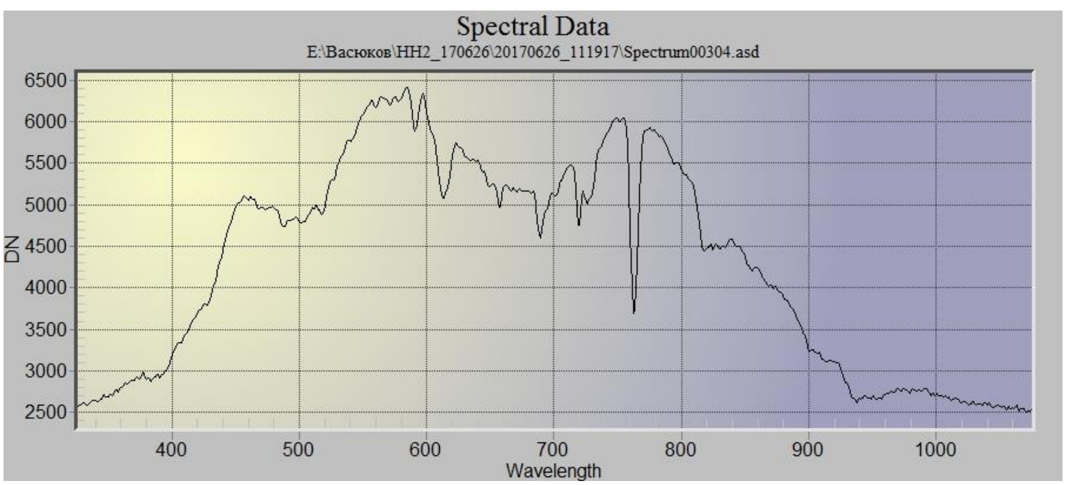

Figure 5. The fifth type of the spectrographic curve.

The analysis did not give clear regularities for all types of spectrograms, except the fourth type (Fig. 4) with approximately same amount of organic matter (humus, %). In other types of spectrograms, the distribution of agrochemical indicators within the type did not show any definite dependencies. The distribution of agrochemical indicators between the types of spectrograms also did not reveal a clear regulaity, with the exception of fourth type. For this type of spectrogram, there is a clear relationship with a reduced amount of humus. This dependence is apparently due to the fact that this type of spectrogram was presented for soil types with an average degree of erosion.

Visual analysis of scales, different types of spectrograms and their comparison with soil varieties revealed an interesting regularity. Different types of spectrograms have different spectral brightness and different intervals in brightness units between the peaks on spectrogram curve. The following regularity is noted, the spectral brightness is much higher and the intervals between the peaks on spectrogram curve in brightness units are much larger for uneroded varieties of soils. So, if for the first type of spectral curve the total brightness at the maximum reaches 13000 units, and the distance between the curve peaks is 4000-5000 units, then for the spectrogram of the third type the total brightness at the maximum is only 4200 units, and the distance between the curve peaks – 200-300 units.

If we bring all types of spectrograms curves to one scale along the ordinate axis (spectral brightness), then with similar types of brightness curves, amplitude for type one, type three, type four, will be less more than 2 times than that of the first type.

Thus, by the types of spectral curves and their spectral brightness it becomes possible to determine the erosion degree for gray forest and chernozem soils of the subboreal belt of eastern part of European Russia. For this, it is necessary to have two reference plots. The first one, with uneroded soil – it will have a maximum brightness amplitude and maximum differences between the peaks of the curve in spectral brightness units. The second one, with medium and high washout degree – curve amplitude and differences between peaks of graph with a similar shape will be minimal; it will be "compressed" relative to the spectral curve for unwashed soil. To assess the degree of soil washout, it is necessary to adjust the spectrometer to a single spectral brightness measuring scale and conduct laboratory soil samples studies in order to reduce the determination error.

4. CONCLUSIONS

1. Simple mechanical mixing of different soil types characteristics does not reveal statistically significant relationships between agrochemical indicators and spectral characteristics of the soil. This is explained by difference in soils genesis and characteristics, which is confirmed by a significant variation in correlation degree between the same pairs of analyzed data in different soils. To obtain a statistically significant picture it is necessary to involve a considerable number of samples from homogeneous soil cover. Accordingly, a sufficiently large number of samples will be necessary for a particular soil variety within the same natural area to automate the process. Statistically significant algorithms will work only in a rather small area without primary data accumulation.

2. Obtained results confirm the hypothesis – there are statistically significant relationships between certain groups of agrochemical indicators and certain soil varieties. This will make possible to automate the process of soils characteristics determining in case of relevant data accumulation for specific soil types.

3. Additional verification of spectrometric materials with laboratory soil analysis data will make it possible to determine soil cover washout degree by spectral curve type and spectral brightness. This approach provides minimal impact on soil, high speed of field survey and significant savings in material resources.

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